On the Physiological Action of some of the Heavy Metals in Mixed Solutions *

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It has been shown by several investigators that, in mixed solutions containing the lighter metals, the physiological action of the electro-positive elements may in a degree antagonize each other, and a mixture of several toxic solutions of these compounds may be much less harmful than any one of the constituents taken singly. Researches concerning the physiology of sea-water have shown this to be conspicuously the case. Work on soil-solutions by Kearney and Cameron † has developed a similar situation.

The neutralizing action of the various ions on those of the heavy metals has been less studied and the present paper presents, in a preliminary way, results gained from a series of experiments performed during the summer of 1902 in the Plant Physiological Laboratory at Wood's Hole, Massachusetts.

As a test object, the primary radicle of seedlings of *Lupinus albus* was used. The method of procedure consisted essentially in suspending the seedlings on glass rods for at least 24 hours in each experiment, in such a manner as to immerse the radicles in the solution under study. In most cases the seedlings were under observation for 48 hours. At least four seedlings were used in each experiment of a series, and our deductions were drawn from the figures for average growth. With only a very few exceptions each member of the quartette manifested the same tendency. The solutions were carefully prepared from pure chemicals and were believed to be very accurate. The experiments were made in beakers.

In order to get a basis for comparison, we made a number of solutions of different compounds of each of the heavy metals used,

* Read by title at the meeting of the Botanical Society of America, held at Washington, D. C., December, 1902.

† Kearney, T. H., and Cameron, F. K. Some Mutual Relations between Alkali Soils and Vegetation. U. S. Dep. Agric. Rep. No. 71. 1902.

and determined the strongest concentration in which the plants were able to make appreciable growth. This point of undoubted growth furnished a point of departure in making comparisons. The

TABLE I

SIMPLE SOLUTIONS.* HEAVY METALS. AVERAGE GROWTH-RATES IN MILLIMETERS †

Conc. Gm. Mol.	$CuSO_4$	$CuCl_2$	$Cu(CH_3CO_2)_2$	$AgNO_3$	$HgCl_2$	$ZnSO_4$
m/8192					2.0	6.0
m/16384	0.5	1.0	1.0		9.0	9.0
m/32768	1.0	1.0	2.0		13.0	18.0
m/65536	3.5	3.0	3.0	2.0	16.0	18.0
m/131072	11.0	10.5	11.0	6.0		16.0
m/262144		16.0	15.0	13.5		
m/524288				22.0		
Check.	14.0	14.0	12.0	12.5	15.0	15.5

* All control experiments in this and subsequent series were made in water which had been very carefully distilled several times. All of the solutions were prepared from distilled water obtained under constant conditions.

† The growth-rates recorded in these tables are those for the first 24 hours.

accompanying tables give the average growth-rates at the end of twenty-four hours.

Table I summarizes the growth-rates obtained in a series of solutions of salts of copper, silver, mercury and zinc. In order

TABLE II

SIMPLE SOLUTIONS. LIGHT METALS AND UREA. AVERAGE GROWTH-RATES IN MILLIMETERS

Conc. Gm. Mol.	NaCl	Na_2SO_4	KCl	KNO_3	$Ca(NO_3)_2$	$CaCl_2$	$CaSO_4$	$MgCl_2$	Urea
m/8						1.5			0.5
m/16	2.5					9.6			1.0
m/32	3.5	1.3	0.7	3.4	20.0	16.0			3.5
m/64	7.5	1.0	2.0	4.0	20.5		35.0		8.0
m/128	13.5	2.8	6.6	8.0	21.0				
m/256		5.8	7.0	9.0	21.0				
m/512								5.5	
m/1024								6.2	
m/2048								9.4	
m/4096								12.5	
Check.	15.5	10.0	10.0	14.0	10.0	12.5	13.0	10.0	15.2

to test the possible antagonizing influence of compounds with other bases, a number of salts of sodium, potassium, calcium and magnesium were used.

A similar point indicating the maximum concentration per-

mitting growth was obtained for each of the salts of the lighter metals taken. This was necessary in order to get some idea of the permissible concentrations in which the latter might be used. Table II presents in brief the growth-rates made by the lupine roots in solutions of the salts of the second group of metals (and of urea).

SIMPLE MIXTURES

Knowing now the effect, on the growth-rate, of the heavy metals under study, also that of the salts of the lighter metals which were made use of, we have a basis for ascertaining the action of these compounds when their solutions are mixed. The method of procedure in this connection consisted briefly in mixing, with a series of graded solutions of the heavy metals, a definite quantity of the salts of the lighter metals. Two general classes of salts could be chosen for this purpose; first, those in which a common anion occurs in combination with the different cations made use of; second, salts in which also the anions differed. By making up solutions molecularly, as was done in every case, a comparison of results obtained from the same cations, combined in the two ways indicated, would enable us to judge of the action of the anions.

Table III summarizes growth-results obtained by growing lupine radicles in a series of solutions of copper salts mixed with salts of one lighter base in varying degrees of concentration. The growth-rates obtained are directly comparable to those resulting from the action of the simple solutions of the heavy metals. It will be noted that when copper sulphate is mixed with calcium sulphate, the latter containing $m/144$ grams per liter, a corresponding growth-rate is found in the case of the simple solution (Table II) at a concentration of copper sulphate indicated by $m/65536$, and in the case of the mixed solution (Table III) at a concentration of $m/16384$. These facts indicate that the presence of the given amount of calcium sulphate enables the plant to withstand four times as much copper as it was able to withstand when the latter occurred in simple solution. A further inspection of the tables shows that when calcium sulphate is present in weaker solutions, the antagonizing action is still strong, even when calcium sulphate is present in a concentration of $m/512$.

When to copper chloride, magnesium chloride is added in a

series of graded concentrations, an inspection of the tables shows that in general little, if any, diminution in the toxic action of the copper follows. This seems to indicate that magnesium is not able to diminish the poisonous action of the copper under the conditions present.

When to copper chloride, calcium chloride is added in the proportion of *m*/128, a decided decrease in the killing power of the copper is seen. When to copper chloride, sodium chloride, *m*/16, is added, a strikingly reversed situation appears. Not only is the harmful action of the copper not diminished, but the mixture seems to be slightly more poisonous than the simple copper solution or

TABLE III

MIXED SOLUTIONS. HEAVY METAL AND LIGHT METAL. COMMON ANIONS. AVERAGE GROWTH-RATES IN MILLIMETERS

Concent. of Solution of Heavy Metal	$CuSO_4 + CaSO_4$			$CuCl_2 + MgCl_2$			$CuCl_2$ + $CaCl_2$	$CuCl_2$ + NaCl	$AgNO_3$ + KNO_3	$HgCl_2$ + $CaCl_2$	$ZnSO_4$ + $CaSO_4$
	$CaSO_4$ *m*/144	$CaSO_4$ *m*/256	$CaSO_4$ *m*/512	$MgCl_2$ *m*/128	$MgCl_2$ *m*/256	$MgCl_2$ *m*/512	*m*/128	*m*/16	*m*/256		*m*/256
m/2048		0.0	0.0								33.5
m/4096	0.0	0.0	0.0							0.0	39.0
m/8192	0.0	0.0	1.0					0.0		0.0	37.5
m/16384	3.0	3.0	1.5	1.0	2.0	2.0	2.0	0.0		1.0	37.0
m/32768	8.5	7.0	3.5	1.0	3.0	1.0	6.0	0.0	1.0	2.0	
m/65536	14.0	17.0	14.0	4.0	4.0	3.0	10.5	0.5	3.0	8.0	
m/131072		19.5				5.0	15.0	1.0	5.0		
Check in water	12.0	11.0	11.0	10.0	14.0	12.0	14.5	12.0	11.5	12.0	13.0
Check in Solution of Light Metal	29.0	26.5	26.0	4.0	9.0	4.5	20.0	1.0		24.5	35.0

the simple sodium solution. This would seem to indicate that to the poisonous action of the copper that of the sodium chloride itself is added.

When to a solution of silver nitrate a solution of potassium nitrate, *m*/256, is added, no very marked change in the action of the heavy metal is noticeable, the growth-rate coinciding approximately with that seen in the solution of the pure silver salt. What difference there is seems to be in the direction of greater toxicity.

When to mercuric chloride, calcium chloride, *m*/256, is added

no diminution in the poisonous action of the corrosive sublimate is seen. Indeed, the mixture is markedly more poisonous than the solution of the simple salt. Zinc sulphate gives a very different result when calcium sulphate, *m*/256, is added. Whereas growth is much retarded in a *m*/8192 solution of zinc sulphate, in the mixture at *m*/2048 growth is more than twice as rapid as in the control grown in water. We have here a very marked stimulation in the growth-rate, resulting from the addition of the lighter metal to the zinc.

When to salts of the heavy metals compounds of the lighter

TABLE IV

MIXED SOLUTIONS. HEAVY METAL AND LIGHT METAL. DIFFERENT ANIONS. AVERAGE GROWTH-RATES IN MILLIMETERS

Concent. of Solution of Heavy Metal	$CuSO_4$ + $CaCl_2$ *m*/128	$CuSO_4$ + $CaCl_2$ *m*/128(dup.)	$Cu(CH_3CO_2)_2$ + $Ca(NO_3)_2$ *m*/32	$HgCl_2$ + $Ca(NO_3)_2$ *m*/32	$CuSO_4$ + Urea *m*/64
m/4096				0.0	
m/8192			2.0	1.0	
m/16384	1.5	3.0	5.0	6.0	
m/32768	3.0	4.0	9.5	16.0	0.0
m/65536	7.0	10.0			0.5
m/131072		16.5			4.5
Check	12.0	15.5	13.0	14.0	11.5

metals are added, in the form of salts in which the anion differs from that in the copper compound, a condition of things is found which is not essentially different from that just cited. In Table IV results bearing on this point are presented.

It will be noted that when calcium chloride, *m*/128, is added

TABLE V

MIXED SOLUTION. COPPER SULPHATE WITH CANE SUGAR. AVERAGE GROWTH-RATES IN MILLIMETERS

Concent. of Copper Solution	Cane Sugar 2*m*	Cane Sugar *m*	Cane Sugar *m*/2	Cane Sugar *m*/4	Cane Sugar *m*/8	Cane Sugar *m*/16	Check in Water
m/65536	0.0	2.7	4.0	7.5	5.5	6.5	15.5

to copper sulphate, a marked diminution in the poisonous action of the copper compound takes place to a degree equal to that seen when the anions are similar. When to copper acetate cal-

cium nitrate, *m*/164, is added, a similar situation results. In the case of solutions of mercuric chloride to which calcium nitrate has been added, we find no amelioration of the poisonous action of the corrosive sublimate, the growth being, if anything, less in the mixed solution than in that of the mercuric chloride alone.

In view of what has been said, the question naturally arises as to the effect of non-electrolytes in solution with the heavy metals. In this connection but two compounds were studied : cane sugar and urea. Tables IV and V present the results obtained. It will be seen that in a solution of copper sulphate, *m*/65536, to which cane sugar in concentrations varying from *m* to *m*/16 has been added, the growth-rate in general increases as the concentration of cane sugar diminishes. The growth-rate is markedly greater in the solution of copper sulphate containing cane sugar varying in concentration from *m*/4 to *m*/16 than in the copper solution alone. This growth-rate was not a persistent feature, however, since in all the mixtures except that containing cane sugar at the least concentration, *m*/16, no growth took place in the second twenty-four hours. It appears, therefore, that when cane sugar is added in proper proportions, as in these experiments, the poisonous action of copper is somewhat diminished. This is probably due to the formation of copper saccharate and a consequent lessening of the number of Cu ions.*

As regards the effect of the addition of urea, *m*/64, it appears that the inhibiting action of the mixed solution is greater than that of the simple copper salt, the addition of the urea seeming to increase the total poisonous action.

COMPLEX MIXTURES

In order further to test the effect of additions of lighter metals to salts of the more poisonous elements, more complicated syntheses were made. These were of two classes : one mixed solution in which all of the salts present had a common anion ; a second mixed solution in which the anion of the salt of the heavy metal did not appear in any of the compounds of the lighter

* See Loeb, J., and Gies, W. J. Weitere Untersuchungen über die entgiftenden Ionenwirkungen und die Rolle der Werthigkeit der Kationen bei diesen Vorgängen. Archiv für die ges. Physiologie, 93 : 261. 1902.

metals. Mixtures were made in which, in addition to a copper salt, salts of sodium, magnesium, calcium and potassium, successively, were added. In every case, Ca excepted, the concentration in which each compound was present was that which, while distinctly retarding growth, still permitted it. We have, therefore, in every case, a salt entering into the combination in a concentration sufficiently great to be a distinctly toxic agent. The concentrations and other data in this connection appear in Table VI.

It will be noted in each case that the copper salt permits a slight growth. When the sodium salt is added, the mixture be-

TABLE VI

COMPLEX MIXTURES OF ONE HEAVY METAL AND AN INCREASING NUMBER OF LIGHTER METALS. AVERAGE GROWTH-RATES IN MILLIMETERS

With common anions									With different anions		
(*a*) Contents of Solutions		Av. Growth 24 hrs.	(*b*) Contents of Solutions		Av. Growth 24 hrs	(*c*) Contents of Solutions		Av. Growth 24 hrs.	Contents of Solutions		Av. Growth 24 hrs.
	mol			mol			mol			mol	
$CuCl_2$	65536	5.5	$CuCl_2$	32768	1.0	$CuCl_2$	65536	2.5	$Cu(CH_3.CO_2)_2$	65536	8.0
$CuCl_2$	65536		$CuCl_2$	32768		$CuCl_2$	65536		$Cu(CH_3.CO_2)_2$	65536	
NaCl	64	2.5	NaCl	64	1.5	NaCl	128	1.0	Na_2SO_4	128	3.0
$CuCl_2$	65536		$CuCl_2$	32768		$CuCl_2$	65536		$Cu(CH_3.CO_2)_2$	65536	
NaCl	64		NaCl	64		NaCl	128		Na_2SO_4	128	
$MgCl_2$	512	7.0	$MgCl_2$	512	2.5	$MgCl_2$	1024	6 0	$MgCl_2$	512	8.0
$CuCl_2$	65536		$CuCl_2$	32768		$CuCl_2$	65536		$Cu(CH_3.CO_2)_2$	65536	
NaCl	64		NaCl	64		NaCl	128		Na_2SO_4	128	
$MgCl_2$	512		$MgCl_2$	512		$MgCl_2$	1024		$MgCl_2$	512	
$CaCl_2$	32	14.5	$CaCl_2$	32	7.0	$CaCl_2$	64	9.0	$CaCl_2$	32	17.0
$CuCl_2$	65536		$CuCl_2$	32768		$CuCl_2$	65536		$Cu(CH_3.CO_2)_2$	65536	
NaCl	64		NaCl	64		NaCl	128		Na_2SO_4	128	
$MgCl_2$	512		$MgCl_2$	512		$MgCl_2$	1024		$MgCl_2$	512	
$CaCl_2$	32		$CaCl_2$	32		$CaCl_2$	64		$CaCl_2$	32	
KCl	128	19.0	KCl	128	5.5	KCl	256	10.0	KNO_3	128	22.0
Check		13.5			10.5			10.5			13.0

comes somewhat more harmful than the copper salt alone. The addition of magnesium to the mixture raises the growth-rate to a point beyond that reached in the copper solution, indicating a slightly beneficial antagonistic effect. When to these the calcium salt is added, the growth-rate immediately assumes practically normal proportions. This neutralizing or antitoxic effect of the calcium is very marked. When to the combination just referred

to the potassium salt is added, the growth-rate is still further increased. In the last mixture we have five salts, each, with the exception of the calcium compound, in a concentration strong enough to interfere distinctly with growth. As a result of their presence together, not only is there no addition of poisonous effects, but a neutralization of toxicity to such degree as to permit in the mixed solution a growth-rate equal to or greater than that seen in the check culture.

When the concentration of copper solution was doubled and the concentration of the other salts left as before, we found that the action of the copper was more slowly overcome, and even in the most complex mixtures studied, the growth-rate was still below that of the check. Apparently, the poisonous activity of the copper in these cases was greater than such as could be neutralized by the quantities of other salts added to it. When, on the other hand, the concentration of the copper solution was kept as in the first instance and the concentration of the lighter salts added was diminished by half, the neutralizing action of the latter was markedly less. In the most complex mixtures under these latter conditions the observed growth-rate only equaled that of the control. Apparently this fact was due to the unneutralized copper action, since each of the other salts present were below a harmful concentration.

Returning, now, to mixtures in which the anion of the copper salt is not duplicated in any of the other salts present, we see a result essentially like that just noted. When to copper acetate, for example, salts of the metals used before are added in quantities equal to those indicated in Table VI, a similar result is seen. The growth-rate in the pure copper salt in this case is somewhat greater, since the $CH_3.CO_2$ anion is slightly less poisonous than the Cl or the SO_4 anion. The addition of the sodium salt again increases the toxicity of the mixture. The further addition of the magnesium salt diminishes the harmful action somewhat, the activity of the mixture being, roughly, the same as that of copper acetate alone. The entrance of the calcium salt, as before, produces a marked acceleration of growth, the rate jumping to a point considerably above the control. The final addition of the potassium salt still further increases this stimulation. As a result of this ex-

periment it appears that it is immaterial here, as before, whether the lighter metals enter the solution in compounds containing an anion common to that of the heavy metal, or whether the anions be different.

DISCUSSION OF RESULTS

From the evidence at hand in these experiments it appears that, in solutions of salts, the conspicuously effective component of the molecule is the cation or the metal. This presumption, raised by the similar physiological effects produced by the cation of various salts of the heavy metals in equimolecular quantities, is strengthened by the action of mixtures containing a salt of the heavy metal with salts of lighter metals.

In case several salts having the same cation are mixed in solution the same lack of conspicuous influence on growth on the part of the anion is to be seen.* It is clear that the effect exerted upon the lupine roots by the salts of the heavy metals tested, differed according to the concentration of the salts. When sufficiently diluted, solutions containing copper, silver, mercury or zinc ions exerted a more or less clearly marked *stimulating* effect on growth. At a greater concentration, perhaps double that causing stimulation, a retarding influence was usually seen, and in a concentration approximately doubling this, growth was much interfered with; and on again doubling the concentration, little or no growth took place.

The effect of adding solutions containing Ca, Mg or Na ions was seen to vary with the character of the cation introduced. In mixtures containing but two salts (Tables III and VI) sodium seemed to show an increased poisonous action as though that of the sodium were added to that of the cation of the heavy metal. When to a solution of copper, a salt of magnesium was added, the mixture seemed to act with nearly the same intensity as the simple solution containing the copper in like quantity, exerting, therefore, little influence on the poisonous activity of the copper. When calcium was added, a marked reduction of the poisonous activity of copper ions was observed, a result seen even more strikingly in

* The physiological action of every dissociated salt in solution is doubtless an expression of the resultant biological effect of its component cations and anions. In these experiments the influence of the cations was predominant.

the case of zinc. Investigations by Swingle,* Clark,† Rumm and others on the action of Bordeaux mixture, although concerning very different proportions from those here involved, all testify to this power of calcium to neutralize the poisonous action of copper. Whereas the presence of calcium reduced the harmful effects of the copper to about one fourth of that seen in the simple copper solution, the antagonizing action of the calcium reduced the toxic action of the zinc to, at most, one sixteenth of that of the simple zinc solution. In the case of silver, the addition of calcium seemed to exert no ameliorating action. As far as the evidence at hand goes, it appears that such ameliorating action as was observed and would be expected stands in an inverse relation to the poisonous activity of the heavy metal.

From the above, as well as from the work of others, it appears conclusive that certain cations in mixed solutions exert a physiological action antagonistic to that exerted by other cations. The question next arises as to the nature of this modification and its seat. Does a mixed solution of calcium sulphate and copper sulphate or copper chloride, for example, produce the change (which brings about this physiological result) by affecting the condition of the copper in the solution outside of the cell, or does it bring about modifications within the cell itself? Is this antagonism an extracellular chemical change or an intracellular physiological change?

We have two sorts of cases to deal with. In the one case the salts have a common anion and in the other case the anions differ. We may set aside any such changes as the formation of double salts or the setting back of molecular ionization in the former case, since it has been shown that like results are seen when the mixed salts have common anions. This would seem to be a probable situation from *a priori* reasoning also, since in most cases the solutions of the salts of the heavy metals were so dilute that practically complete ionization took place. In that event, no matter what its associated anion was, the metal acted as free ions.

* Swingle, W. T. Bordeaux Mixture. U. S. Dep. Agric. Div. Veg. Path. and Physiol. Bull No. 9. 1896.

† Clark, J. F. The Toxic Properties of some Copper Compounds with special reference to Bordeaux Mixture. Bot. Gaz. **33** : 26. 1902.

In the cases of our mixtures of salts having different anions, chemical reactions might be regarded as possible, with a consequent change in the forms of molecules. Here again, however, the great dilution of the salt of the heavy metal in our most important mixtures produced complete or nearly complete ionization, the heavy metal acting practically as free ions. We can then hardly regard changes of an ordinary chemical nature as being responsible for the differences in the physiological results. We think that interior physiological modifications are responsible for the observed differences in growth rate. This belief implies that the simple salt of the heavy metal and the mixture of this salt with that of a lighter metal, after penetration into the cell, affect the processes there being carried on in such a way as to bring about different results on cellular growth. In studying the effect on growth of simple solutions of copper and calcium salts, for example, we see that at the concentrations employed copper retards growth whereas the calcium salts greatly stimulate it. With each we have, in all probability, to do with antagonistic phases of physiological action. When we examine the results in cases like the above, it seems highly probable that the so-called antitoxic action of ions is due to different interior physiological modifications, and that the growth-rate observed in such experiments as these represents the physiological sum of oppositely acting stimuli, or of antagonistic protoplasmic changes.*

It has been shown that when salts of heavy metals are sufficiently dilute they exert a *stimulating* effect on growth, and when solutions of calcium and similar salts are concentrated enough, they hinder or entirely prevent growth, and may, in the case of the more soluble chloride and nitrate, prove fatal. Coupin † has shown that at different dilutions compounds exhibit *three distinct phases of physiological action*. When the solution is sufficiently dilute it seems too attenuated to produce any effect on growth. As the concentration increases, a *stimulating* phase is seen, which, on further concentration, passes over into the *retardation* phase — pronounced in proportion to the concentration.

* Loeb and Gies, *l. c.*, 267.

† Coupin, H. Sur la toxicité du chlorure de sodium et de l'eau de mer e l'égard des végétaux. Rev. Gén. Bot. 10: 177. 1898.

In the mixtures of copper and calcium employed in our experiments, we may have had concentrations of each salt in different phases of action due to the degree of concentration. In $CuCl_2$, *m*/65536, we see that the Cu concentration is in the phase hindering growth, the resulting elongation of the root being about 3 mm. When $CaCl_2$, *m*/128, was tested, it was found to be in a concentration markedly stimulating when referred to the control in water, growing 20 mm. in the former case, against 14.5 mm. in the check. These opposite tendencies were brought together in the mixed solution with the result that the concentration (in terms of the copper salt permitting the growth-rate seen in the simple copper solution) moved up to approximately four times that observed in the simple copper solution. The stimulating action of the calcium seems to have operated against the retarding action of the copper, and the result is a marked diminution in the poisonous action of the copper.

The opposite result is seen in the mixture containing $CuCl_2$ and NaCl. The latter is in its growth-retarding phase until more dilute than *m*/128. Hence at *m*/16 it is in its growth-retarding phase, and when added to $CuCl_2$ at *m*/65536, likewise in this phase, the result is a sum of toxicity and an increased depression of growth-rate follows the combined action of the two. This also applies to the mixtures containing magnesium.

In considering the more complex mixtures of salts, indicated in Table VI, the chemical nature and influences of the resulting solutions are not readily determined. Much more concentrated solutions result in such mixtures with consequent decrease in dissociation. The probability that we are dealing with various kinds of non-ionized molecules, as well as with an indefinite number of ions, makes it impossible to speak definitely with confidence of the significance of our results in this connection. In general one may say that here, as in sea water, another complicated mixture of molecules and ions, the entrance of the calcium salt into the mixture is the stage in the synthesis at which the growth-rate approaches that seen in the check, and the final addition of the potassium salt seems further to increase the growth-rate. Or, in other words, all the salt solutions except the calcium entered the mixture in a concentration at which singly they would cause a

retardation of the growth-rate without bringing it to a standstill. Of the compounds present, therefore, the calcium salt only entered in a concentration representing the stimulus phase. The marked effect following the entrance of the calcium and the potassium may, in part, be due in these experiments to the cumulative increase of concentration of the solution, with the corresponding decrease in the rate of ionization and the diminished number of active ions. The fact that the potassium salt, although added in a concentration hindering growth when taken singly, increased the growth-rate when added to the mixture as its last member, seems to strengthen this supposition. Of course, changes of this nature represent changes in the solution itself and lie outside of the cell, and should not be confused with the mutually antagonistic intracellular action of ions in the case of very dilute solutions.